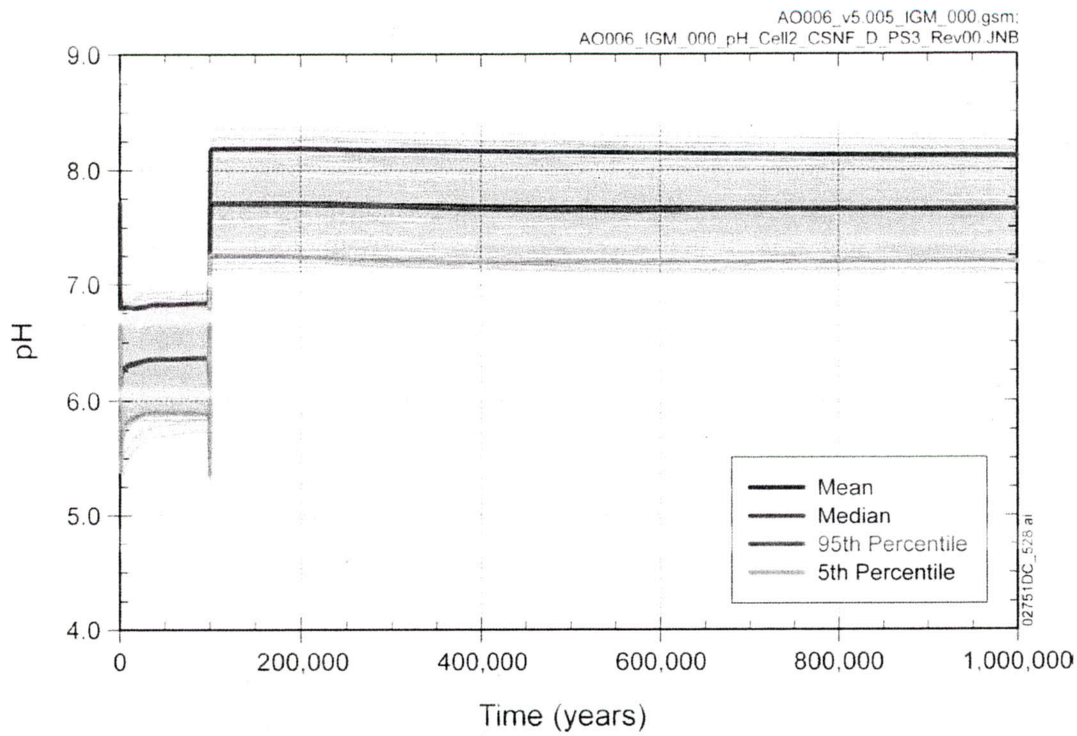

Figure 1.2.1-12. pH in the Corrosion Products Domain of a Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 after an Igneous Intrusion Event at 100,000 Years

1.2.2 1,000,000-Year Seismic Ground Motion Modeling Case

In the seismic ground motion modeling case, the drip shields and waste packages fail in response to both seismic events and/or nominal corrosion processes. Nominal waste package failure processes, which include stress corrosion cracking and general corrosion, result in a gradual failure of waste packages through time whereas seismic processes (stress corrosion cracks, puncture, and/or rupture) are assumed to breach all waste packages simultaneously in a percolation subregion. Following an initial waste package breach by any mechanism, the waste form in that waste package begins to degrade over time. At 1,000,000 years and averaged over all aleatory samples, the expected number of failed commercial SNF waste packages in the seismic ground motion modeling case is about 56% (SAR Figure 2.1-12a). The fractions of waste packages failed by different mechanisms are discussed in the response to RAI 3.2.2.1.4.1-001.

For the 1,000,000-year seismic ground motion modeling case, the expected annual dose for each epistemic uncertainty vector is calculated from thirty aleatory uncertainty vectors, corresponding to different randomly-generated sequences of seismic events using the techniques outlined in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Appendix J, Section J8.4). The TSPA sample size for epistemic uncertainty is 300 and therefore there are 9000 unique random sequences of seismic events in the performance assessment calculations. For the analysis of ^{242}Pu releases presented here, a seismic event history corresponding to realization 4641 (SAR Figure 2.4-92) was selected to isolate key EBS behavior. All dependent variables or quantities analyzed in the following discussion (e.g., cumulative releases or release rates) are conditional on this sequence, i.e., they are not expected values. These dependent variables are also plotted per failed commercial SNF waste package, so they are independent of the number of failed packages and of the seepage fraction in a given realization. Thus, for failures induced only by nominal processes, the quantity plotted may be based on only a few failed waste packages in the repository, while for seismic-induced failures, the quantity will generally be based on all waste packages (since seismic processes generally fail all waste packages simultaneously, although there can be slight differences among the percolation subregions).

Figure 1.2.2-1 shows the cumulative mass of ^{242}Pu released (accounting for radioactive decay) from the waste form matrix (also called the "source term"), the waste form domain, and the corrosion products domain, per failed waste package, conditional on aleatory sequence 4641. Figures 1.2.2-1(b, c, d) show the epistemic uncertainty in cumulative mass release for each domain along with various statistics, such as mean and median, while Figure 1.2.2-1(a) shows a comparison across the three sources/domains of the mean over epistemic uncertainty, conditional on aleatory sequence 4641. The individual realizations in Figures 1.2.2-1(b, c, d) are for the "representative failed commercial SNF waste package" in the seeping environments of percolation subregion 3 in the TSPA model. The release rates shown in each individual realization represent a convolution of the waste form degradation rate with the waste package failure rate for nominal and seismic processes, but primarily reflect the former since release rates are per failed waste package. For example, consider Figure 1.2.2-1(b) for releases from the waste form matrix. Each of the 300 gray curves has a different sampled value of the epistemically uncertain commercial SNF waste-form degradation rate. This can be seen by the variable slopes apparent in the initial rise of each of these curves. For the earliest realization, with initial waste package failure occurring at about 75,000 years, it is apparent that the commercial SNF waste-form degradation rate is very rapid. Other individual curves exhibit a slower commercial SNF waste-form degradation rate.

The integration of the commercial SNF waste package failure rate into each waste form degradation history can generally only have a noticeable effect for nominal processes, since a damaging seismic event will fail all waste packages (i.e., expose all waste forms) simultaneously in a percolation subregion. For nominal failures, incremental failure of the waste packages in a percolation subregion (probably by stress corrosion cracking in the lid welds) is represented as a running average for a representative waste package in the TSPA model. This can actually cause a down-dip in the cumulative release curves, as indicated by the dip at 300,000 years in the plots (Figures 1.2.2-1(a, c, d)). This is caused by the coarse timestepping in the waste package degradation model (see SAR Section 2.4.2.2.3.1), which causes a set of newly failed waste packages with undegraded waste to be averaged with a set of previously failed waste packages with degraded waste.

The gradual increase in the mean curves on Figure 1.2.2-1(a) is primarily a result of the epistemic uncertainty in the time of first failure, conditional on aleatory sequence 4641. However, the spread between the three curves in Figure 1.2.2-1(a) is due to the transport delay across the three sources/domains, which is caused by precipitation, sorption on corrosion products, and, to a lesser degree, flocculation of commercial SNF waste form colloids. Uncertainty in these three processes can be seen by comparing the spread of the gray curves in each of Figures 1.2.2-1(b, c, d), at 1,000,000 years. Among realizations with failed waste packages, there is little spread in Figure 1.2.2-1(b), since the commercial SNF waste-form degradation rates are relatively rapid compared to the time frames shown, and the range of uncertainty in waste mass is relatively small. However, the uncertainty in plutonium solubility does create additional spread in the release rates of ^{242}Pu from the waste form domain, as shown in Figure 1.2.2-1(c). Also, the uncertainty in various parameters affecting plutonium sorption onto stationary corrosion products, as well as uncertainty in the stability of commercial SNF waste form colloids, causes further spread in the release curves from the corrosion products domain, as shown in Figure 1.2.2-1(d); however, most of the spread in Figure 1.2.2-1(d) is caused by uncertainty in waste package failure parameters (see Figure K7.7.2-2[a] in SNL 2008).

Because of precipitation in the waste form domain, only a fraction of the ^{242}Pu mass that is released from the waste form matrix is transported from the waste form domain to the corrosion products domain, predominantly by diffusion of aqueous ^{242}Pu (Figure 1.2.2-2). A much smaller amount of mass is transported irreversibly attached to commercial SNF waste form colloids (Figure 1.2.2-3). This is because, compared to the igneous intrusion modeling case, there are fewer realizations with stable commercial SNF waste form colloids in the waste form domain (compare Figures 27(b) and 6(b) from the response to RAI 3.2.2.1.3.4-2-003). The difference in the stability between the two modeling cases is caused by differences in the ionic strength in the waste form domain due to the nature of the failure mechanisms. Whereas the igneous case treats all waste packages as completely destroyed and open to the percolation flux, advective flux through the stress corrosion cracks in the waste package is screened out in the seismic ground motion modeling case, and therefore, a high in-package ionic strength is maintained in the waste package, and thus does not result in any realizations with stable colloids prior to 400,000 years (Figure 1.2.2-3). The majority of the ^{242}Pu mass that is released from the waste form matrix (i.e., "source term") is retained in the waste form domain as precipitated mass (Figure 1.2.2-4). The nominal waste package failures due to stress corrosion cracks in the lid welds, and the seismic failures due to stress corrosion cracks in seismically damaged areas of the waste package, tend to maintain the dissolved concentration at the solubility limit primarily by restricting water availability.

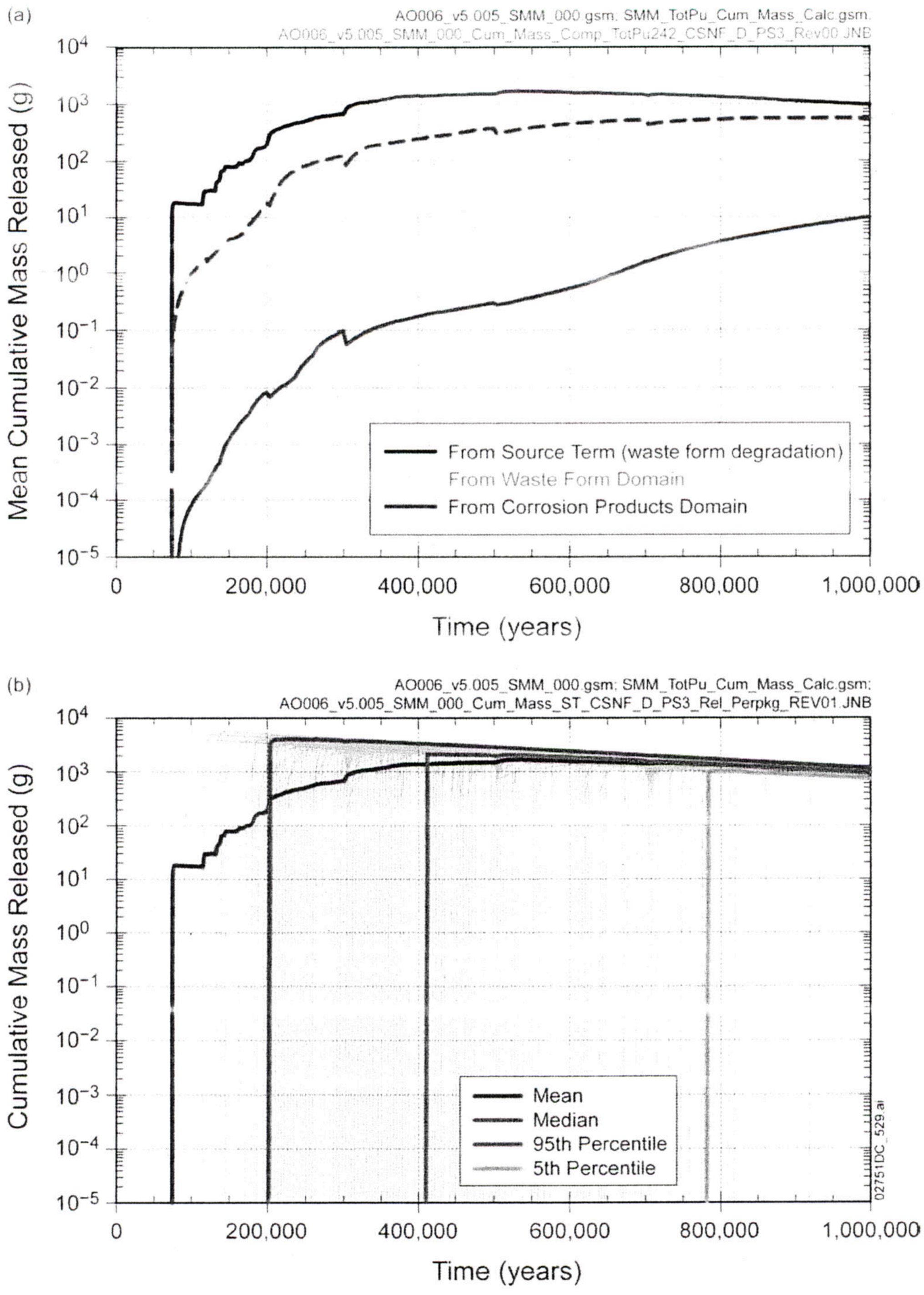

Figure 1.2.2-1. Cumulative Mass of ^{242}Pu Released per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 Conditional on Aleatory Uncertainty Vector 4641 for (a) Mean Releases; Mean Releases from (b) Source Term; (c) Waste Form Domain; and (d) Corrosion Product Domain

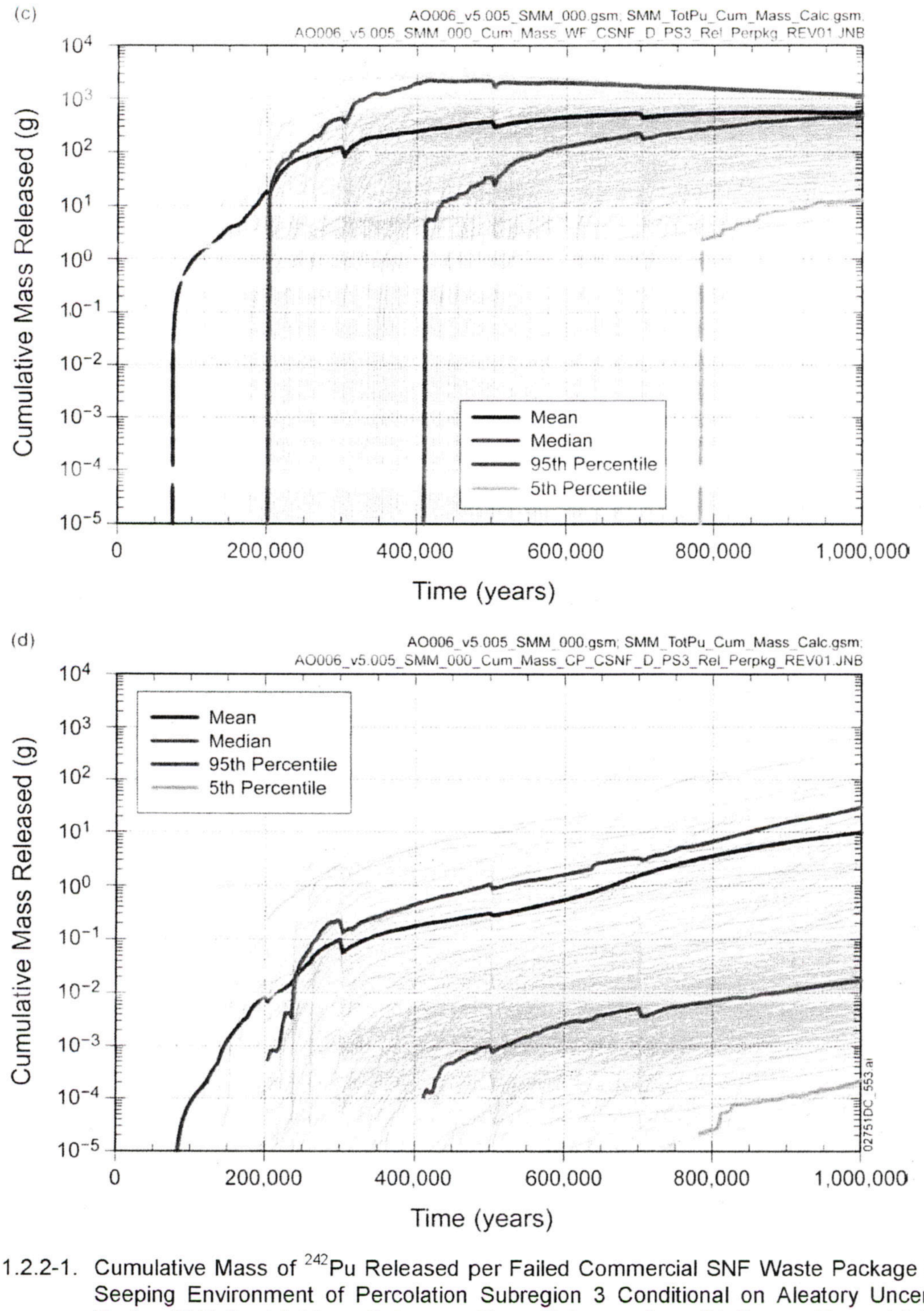

Figure 1.2.2-1. Cumulative Mass of ^{242}Pu Released per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 Conditional on Aleatory Uncertainty Vector 4641 for (a) Mean Releases; Mean Releases from (b) Source Term; (c) Waste Form Domain; and (d) Corrosion Product Domain (Continued)

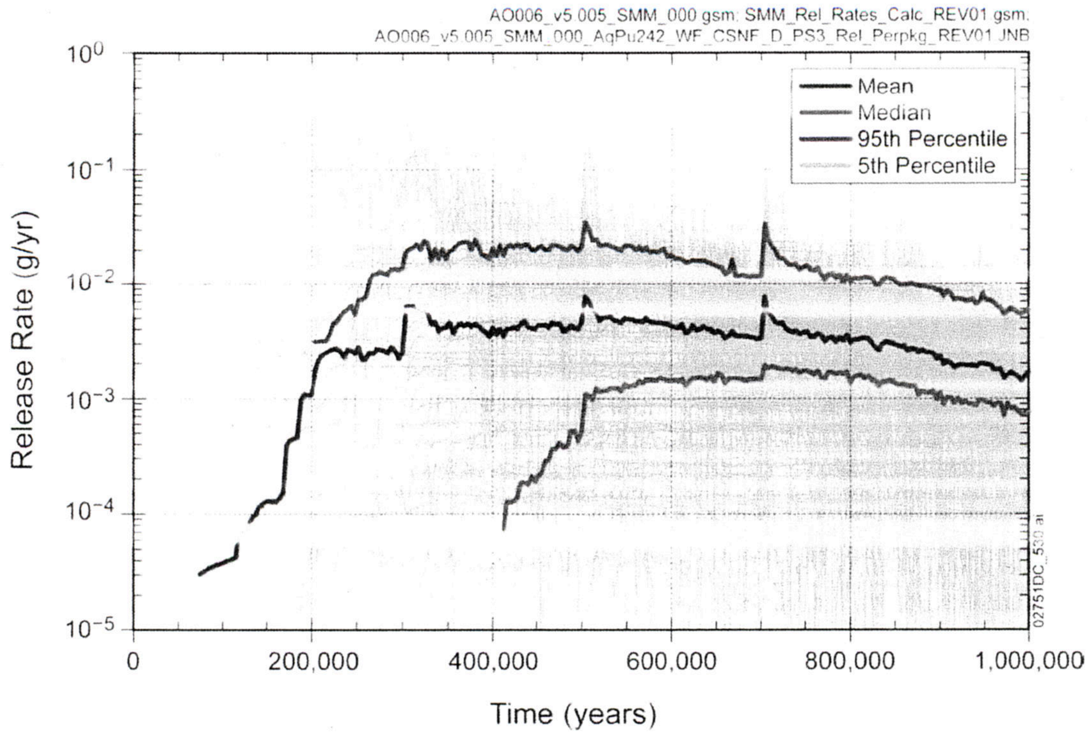

Figure 1.2.2-2. Release Rate of Aqueous ^{242}Pu from the Waste Form Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

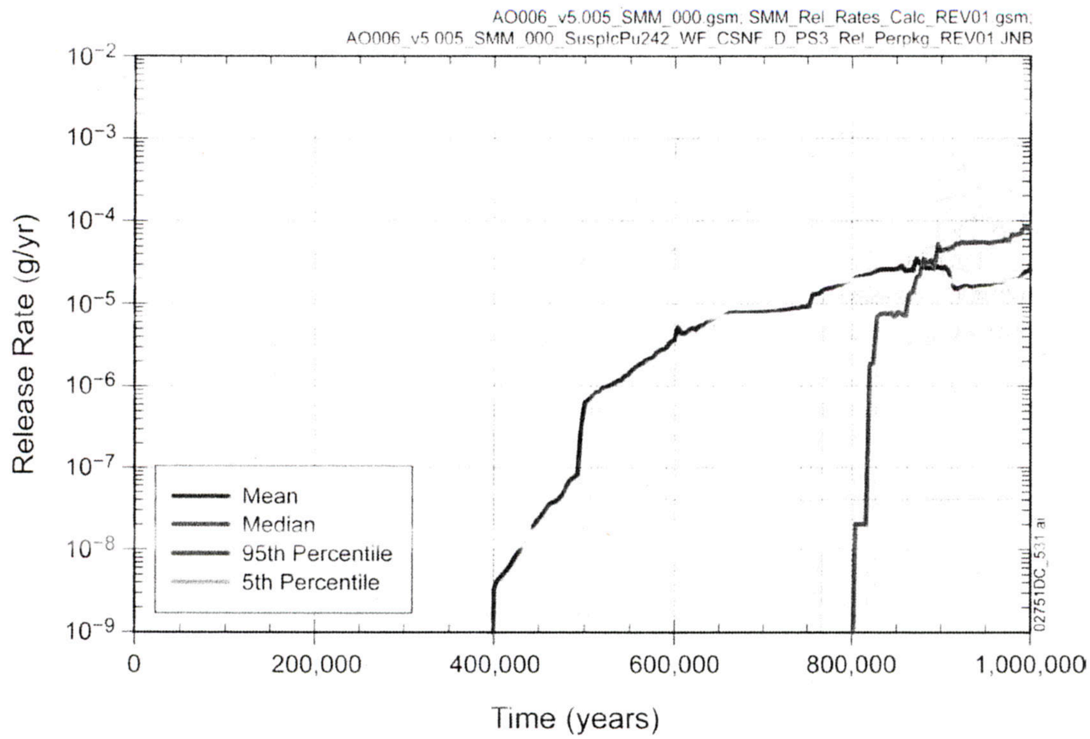

Figure 1.2.2-3. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from the Waste Form Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

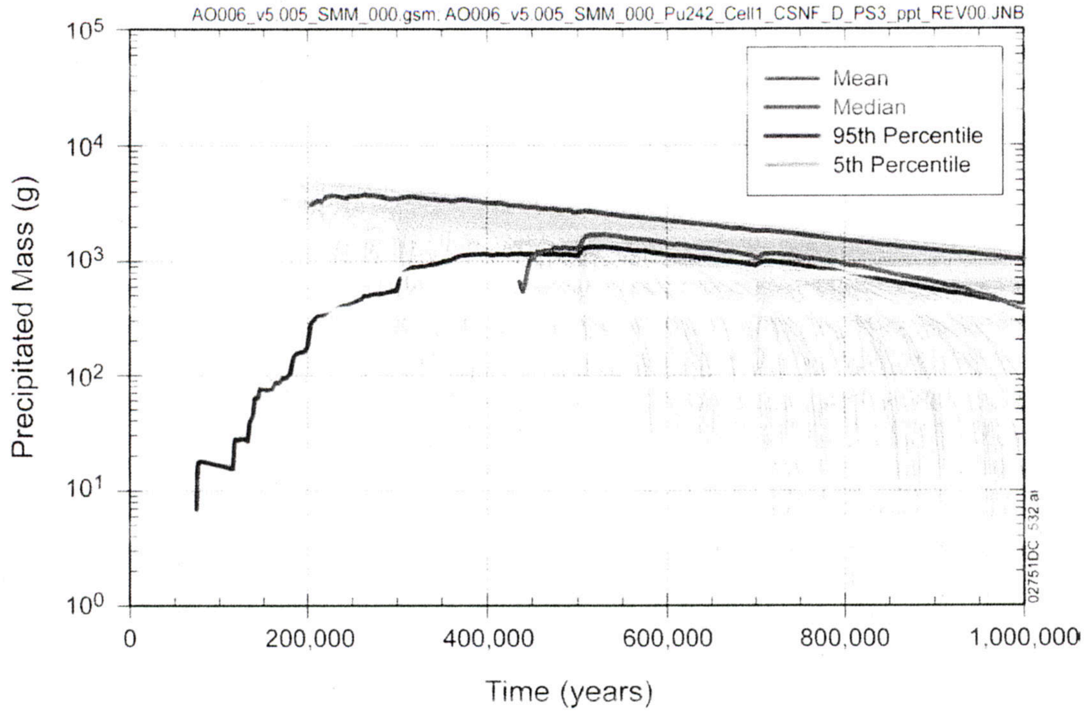

Figure 1.2.2-4. Mass of Aqueous ^{242}Pu Precipitated in the Waste Form Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

Mass that enters the corrosion products domain as aqueous ^{242}Pu is:

- Transported through and released from the domain as aqueous ^{242}Pu (Figure 1.2.2-5);
- Transported through and released from the domain irreversibly attached to FeO_x colloids (Figure 1.2.2-6);
- Immobilized in the domain by re-precipitation, and possibly re-mobilized by re-dissolution (Figure 1.2.2-7); or
- Retarded in the domain by reversible sorption onto stationary corrosion products (Figure 1.2.2-8).

Mass that enters the corrosion products domain irreversibly attached to commercial SNF waste form colloids is:

- Immobilized in the domain by the commercial SNF waste form colloids becoming unstable and settling, and only re-mobilizing to sustain the minimum concentration of waste form colloids (Figure 1.2.2-9).

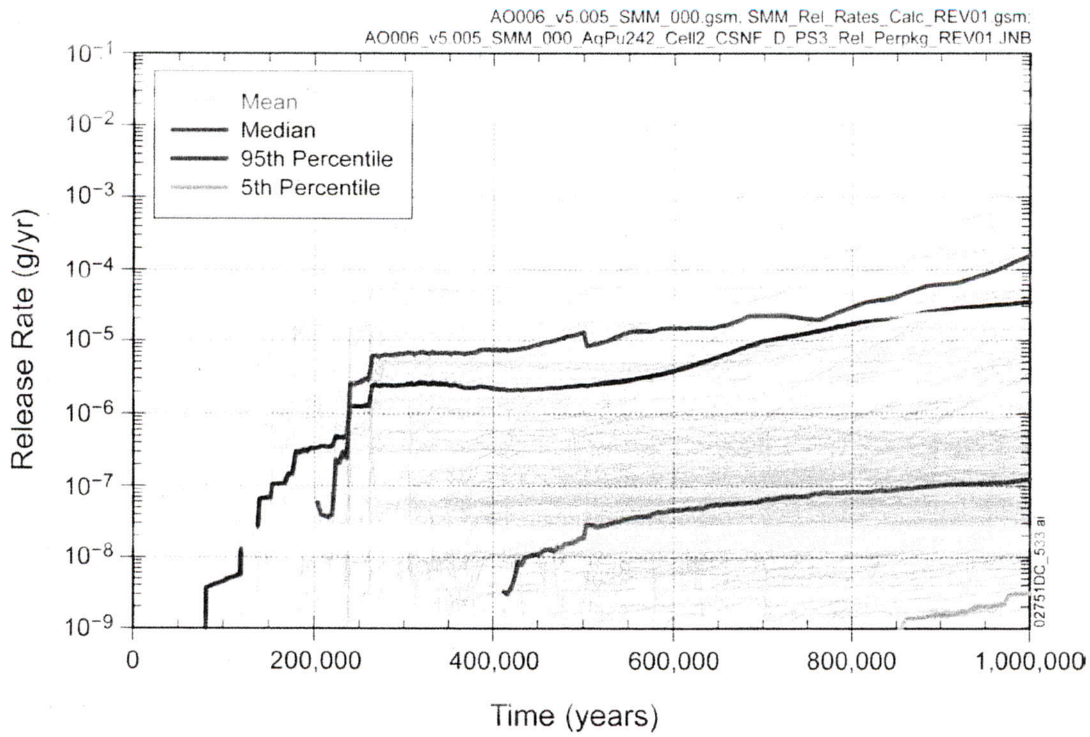

Figure 1.2.2-5. Release Rate of Aqueous ^{242}Pu from the Corrosion Products Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

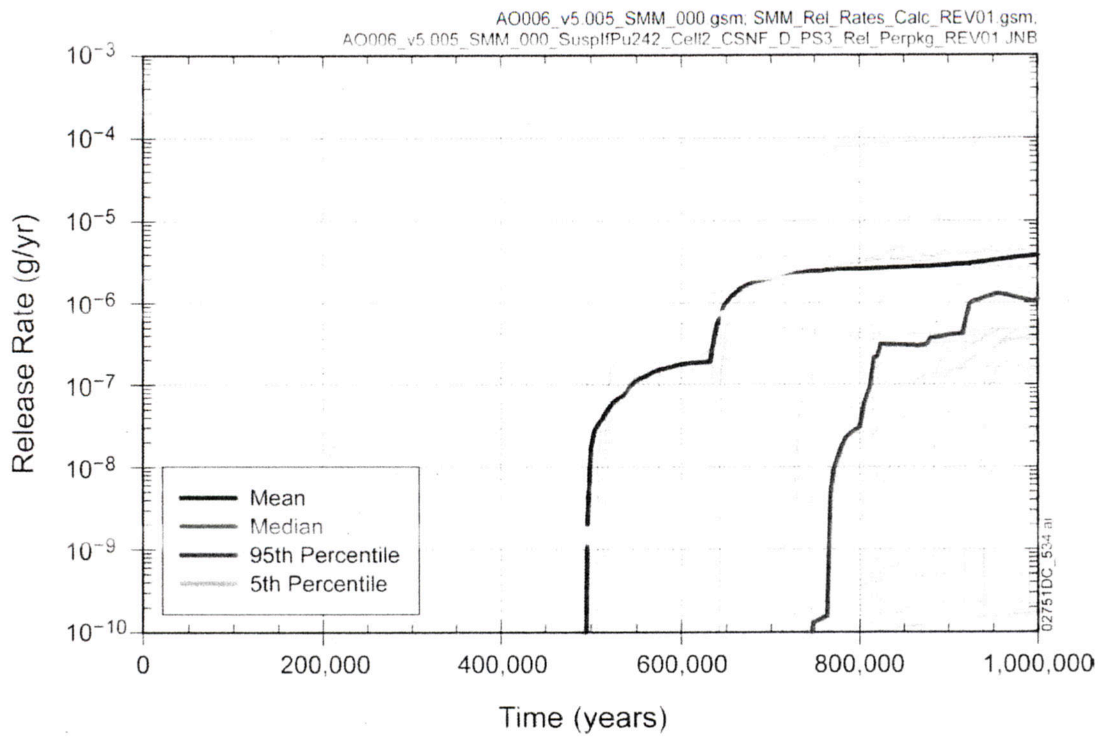

Figure 1.2.2-6. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from the Corrosion Products Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

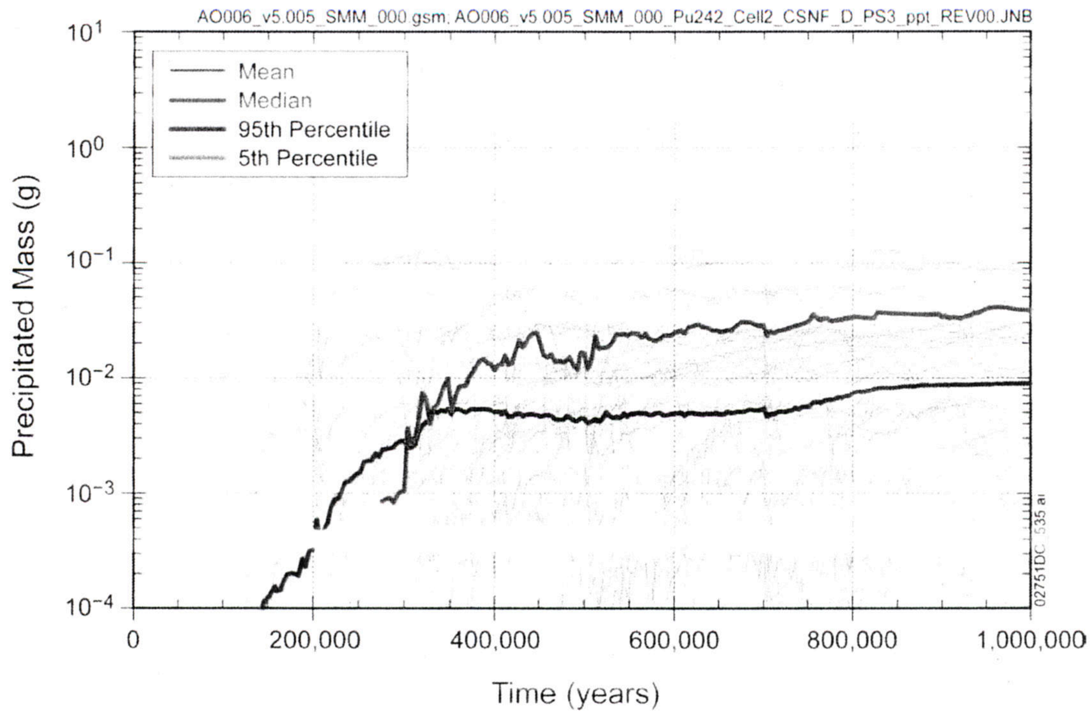

Figure 1.2.2-7. Mass of Aqueous ^{242}Pu Precipitated in the Corrosion Products Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

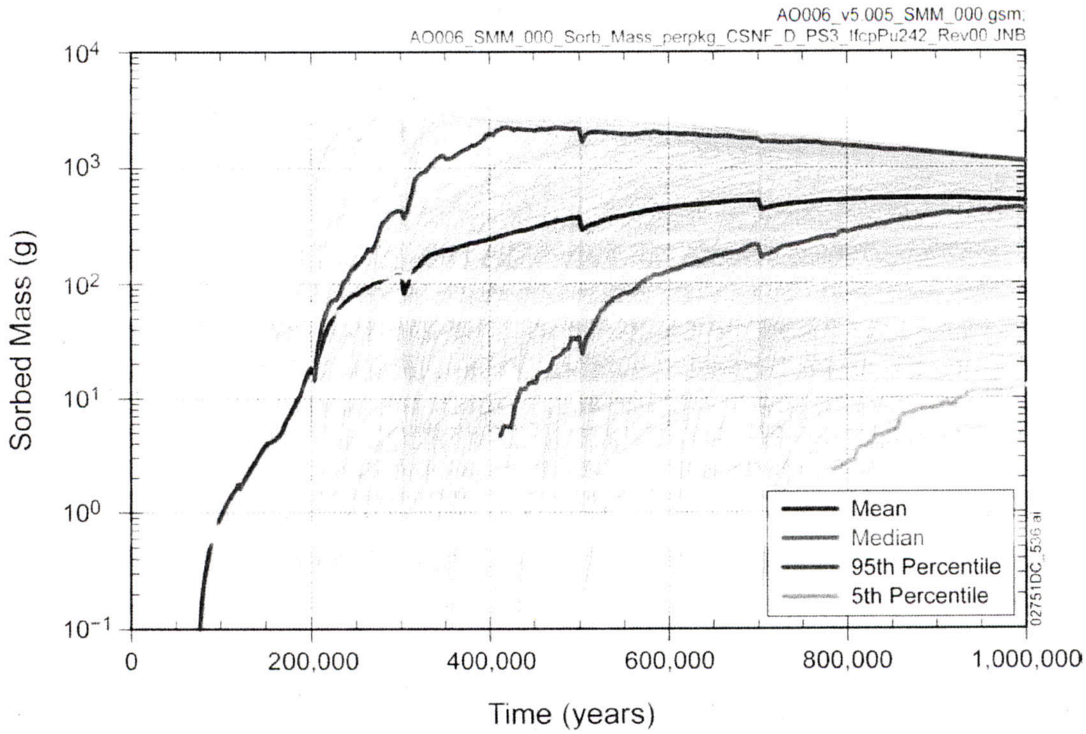

Figure 1.2.2-8. Mass of ^{242}Pu Reversibly Sorbed onto Stationary Corrosion Products in the Corrosion Products Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

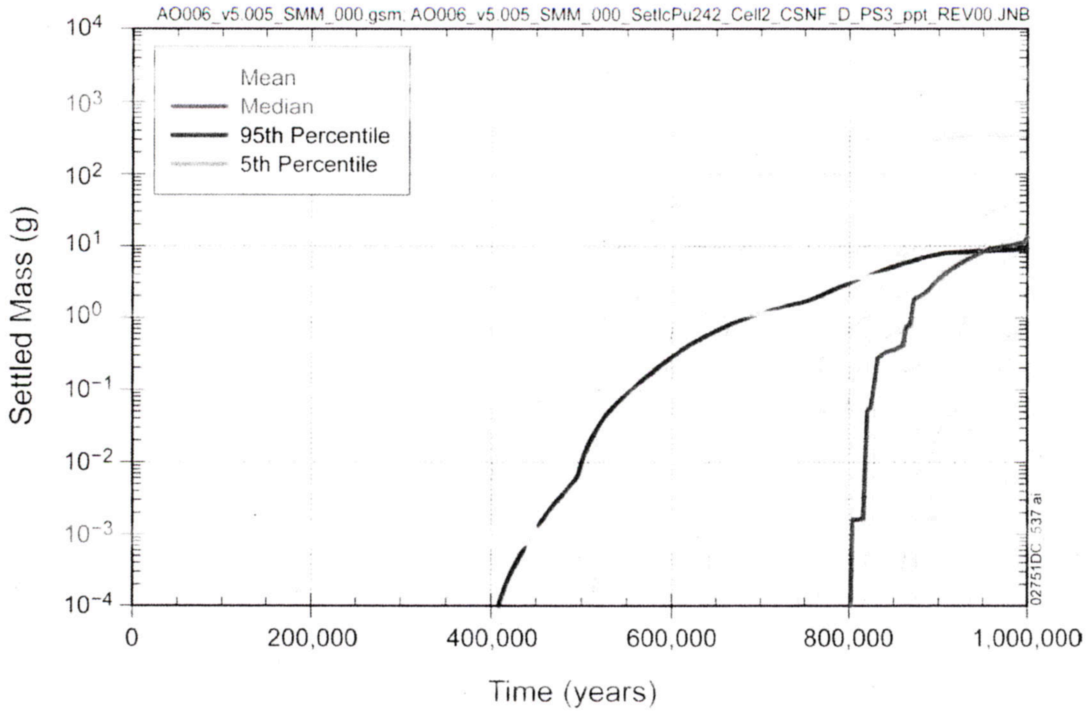

Figure 1.2.2-9. Mass of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids Settled (Unstable) in the Corrosion Products Domain per Failed Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

As mentioned above, for the seismic ground motion modeling case, the mean behavior of the cumulative mass release curves is controlled by epistemic uncertainty in the time of failure of waste packages across the individual realizations. For this reason, a table similar to Table 1.2.1-1 is not meaningful in the seismic case. For example, consider the entry in Table 1.2.1-1 for precipitated mass in the waste form domain at 200,000 years. The comparable entry for the seismic ground motion case does not have the same physical meaning due to the fact that the various epistemic realizations have waste package failures at different times. This number for the seismic ground motion case would be a risk-weighted mass, i.e., the product of the (epistemically uncertain) probability that there is a waste package failure and the average mass if there were a failure (and conditional on aleatory sequence 4641). Because this quantity does not have a clear physical meaning as in the igneous modeling case, it is not presented for the seismic ground motion modeling case. Individual realizations in Figures 1.2.2-1(b, c, d) may be compared across the three sources/domains. This comparison shows the retardation of ^{242}Pu releases due to precipitation and sorption processes.

Comparison of the pH in the waste form domain (Figure 1.2.2-10) to the pH in the corrosion products domain (Figure 1.2.2-11), for the seismic ground motion modeling case, indicates the effect of pH buffering in the corrosion products domain. However, as described previously, not many of the seismic ground motion modeling case realizations have stable waste form colloids in the waste form domain, so the pH buffering does not result in a significant mass of ^{242}Pu irreversibly attached to settled commercial SNF waste form colloids in the corrosion products domain compared to the igneous intrusion modeling case. (Note that the early-time values of pH on Figure 1.2.2-11, prior to waste package failure, are not significant. These are simply initial values or estimates. Figure 1.2.1-12 for the igneous case indicates the same range of initial values between about 5.5 and 7.0, prior to the igneous event at 100,000 years.)

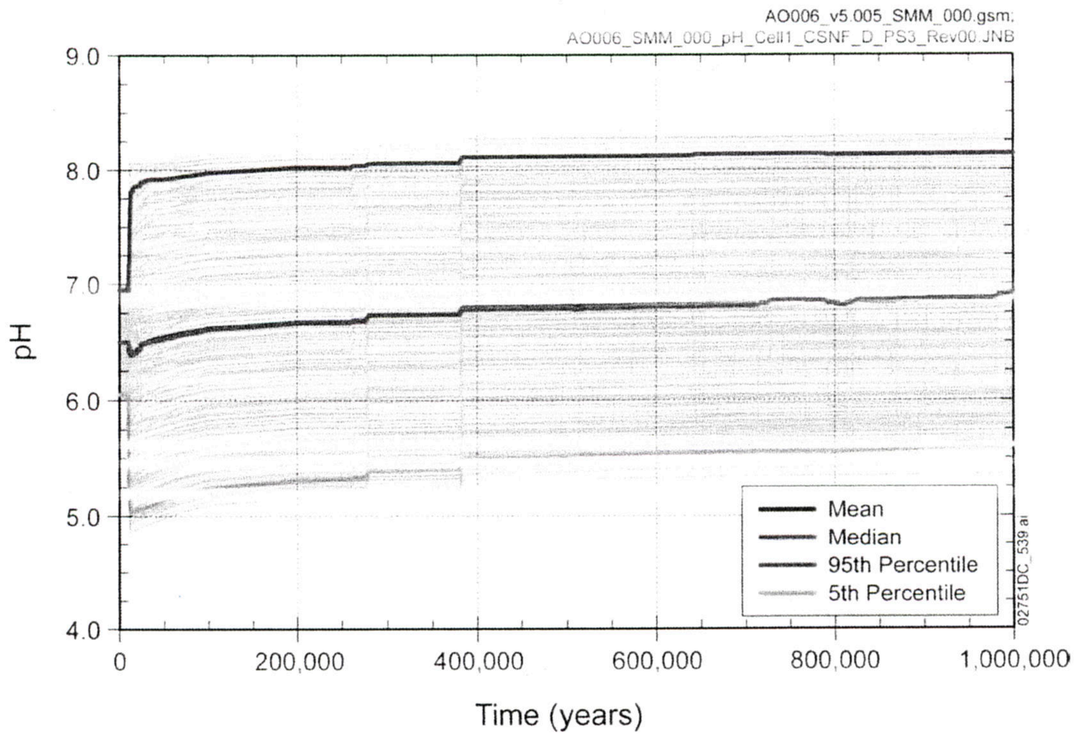

Figure 1.2.2-10. pH in the Waste Form Domain of a Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

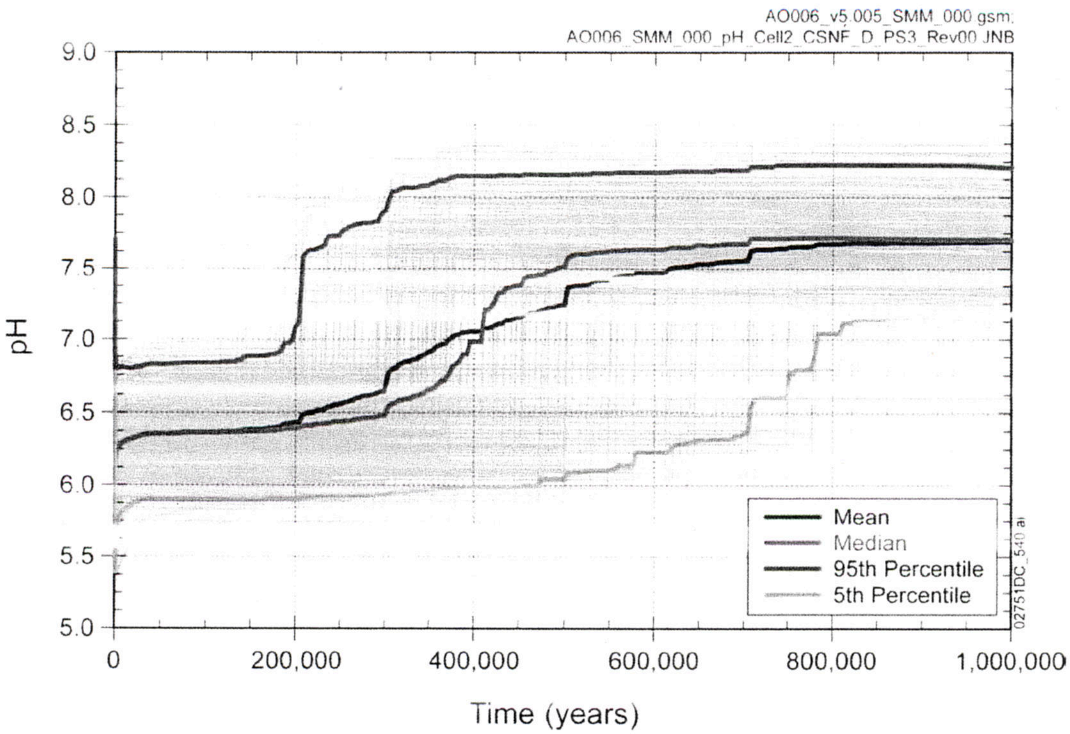

Figure 1.2.2-11. pH in the Corrosion Products Domain of a Commercial SNF Waste Package in the Seeping Environment of Percolation Subregion 3 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure Conditional on Aleatory Uncertainty Vector 4641

1.3 SUMMARY

Stationary corrosion products primarily affect the timing and magnitude of plutonium release by sorbing plutonium and buffering pH. Plutonium sorption retards the release of plutonium from the corrosion products domain. The pH buffering in the corrosion products domain further inhibits plutonium release by causing plutonium-bearing colloids to become unstable and settle out.

At 1,000,000 years in the igneous intrusion modeling case for an igneous event at 100,000 years, 70.2% of the undecayed ^{242}Pu mass in a commercial SNF waste package, on average (over epistemic uncertainty, conditional on an event time at 100,000 years), has been released from the corrosion products domain. The retained ^{242}Pu mass is present in the corrosion products domain as sorbed onto stationary corrosion products (3.8%) and irreversibly attached to settled waste form colloids (19.4%), and in the waste form domain as precipitated mass (6.5%) (Table 1.2.1-1). Therefore, at 1,000,000 years in the igneous intrusion modeling case, the stationary corrosion products contribute to the retention of 23.2% of the undecayed ^{242}Pu mass. The mass sorbed (3.8%) is relatively small due to net desorption that occurs after about 200,000 years, concurrent with reductions in aqueous concentration in the corrosion products domain in those realizations with higher plutonium solubilities, which have a more rapid depletion of plutonium mass from the waste form domain (the source term for plutonium in the downstream corrosion products domain). The mass attached to settled commercial SNF waste form colloids (19.4%) is relatively large due to the prevalence of stable waste form colloids in the waste form domain in 38% of realizations and subsequent pH buffering in the corrosion products domain, which causes the waste form colloids to flocculate in the corrosion products domain.

The mean behavior of mass release and mass retention in the seismic ground motion case, conditional on aleatory sequence 4641, is controlled by epistemic uncertainty in the timing of waste package failures across the realizations. Thus, generalities about physical processes cannot be easily derived from the mean time histories, as was the case with the igneous intrusion modeling case. However, precipitation and sorption still play a large role in plutonium retardation in the EBS, with less of a role played by colloid flocculation because of the relatively few realizations with stable waste form colloids in the waste form domain, in turn due to the relatively higher ionic strength in the seismic case compared to the igneous case.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2007. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071004.0001; LLR.20080414.0023.

SNL 2008. *Total System Performance Assessment Model /Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001.

RAI Volume 3, Chapter 2.2.1.4.1, First Set, Number 3:

Clarify the technical basis for the values used to represent the tephra volume for the volcanic eruption modeling case.

Basis: The SAR provides an estimated range for the total volume of past eruptive events of 0.004 to 0.12 cubic kilometers (Table 2.3.11-2). The SAR also states that the tephra volume is expected to be significantly less than the total volume (i.e., tephra volume estimated for the Lathrop Wells is 0.07 cubic kilometers versus 0.12 cubic kilometers for the total volume – page 2.3.11-50). Implementation of the eruptive modeling case in the TSPA has minimum and maximum values of 0.004 and 0.14 cubic kilometers for use in developing inputs for the ASHPLUME code. These minimum and maximum values reflect the total volume not the tephra volume. Only the latter is significant to the dispersal of radionuclides entrained in tephra. This information is needed to determine compliance with 10 CFR 63.114.

1. RESPONSE

Development of the tephra volume parameter for the total system performance assessment (TSPA) volcanic eruption modeling case is described in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (SNL 2007a, Section 6.3.4.4). While the total volume of past eruptive events shown in SAR Table 2.3.11-2 was considered for describing the characteristics of potential eruptive activity at Yucca Mountain, values for minimum and maximum tephra volume for input to the TSPA model were not based on the range of values provided in that table. Rather, the minimum and maximum tephra volumes used in the TSPA model were based on characteristics of Northeast Little Cone and the Lathrop Wells volcano.

Tephra fall volumes are generally about two times the associated cone volumes based on analogue data (SNL 2007a, Section 6.3.4.4). At Lathrop Wells volcano, estimated tephra fall volume is about 0.07 km^3 and the cone volume is 0.02 km^3, for a tephra/cone ratio of 3.5. The volume of lavas at Lathrop Wells is 0.03 km^3, for a total volume of eruptive products from that volcano of about 0.12 km^3. The minimum value for tephra volume was developed using a similar tephra/cone ratio for Northeast Little Cone, the smallest volcanic cone in the Yucca Mountain region. Using a tephra/cone ratio of 4.0 (similar to the tephra/cone ratio for Lathrop Wells) and an estimated cone volume of 0.001 km^3 for Northeast Little Cone, the minimum potential volume of tephra fall was chosen to be 0.004 km^3. The maximum potential volume of tephra fall was estimated from the Lathrop Wells data by doubling the volume of estimated tephra fall from that volcano. This volume, 0.14 km^3, represents a tephra/cone ratio of 7.0 compared with the Lathrop Wells cone volume. This value is intended to capture the upper end of the range of uncertainty in the potential maximum tephra fall that could be experienced in the Yucca Mountain region.

Tephra volume is not a direct input parameter to the TSPA ASHPLUME model. Minimum and maximum values of tephra volume are used to provide limits on the sampled eruption duration distribution by considering the relationship between eruption power, eruption volume and eruption duration (SNL 2007b, Equations 8-1a and 8-1b). The eruption duration, along with eruption column power, as determined by the eruption mass flux and heat content, are used as direct inputs to the ASHPLUME model to determine the total mass of erupted tephra (SNL 2007b, Equations 6-2, 6-7b, and 6-7c). The eruptive power distribution used in the ASHPLUME model is derived from observations at analogue volcanoes (SNL 2007b, Sections 6.5.2.1). Limits on the range of possible eruption durations for a single model realization, given a sampled value for eruptive power, are established at run-time by considering the minimum and maximum values of tephra volume (SNL 2007b, Equations 8-1a and 8-1b). The limits are imposed to constrain the eruptive mass flux to values consistent with the minimum and maximum values of tephra volume discussed above.

A distribution of tephra volumes equivalent to that used in the TSPA volcanic eruption modeling case was developed for this response using the equations that constrain eruptive mass flux (SNL 2007b, Equations 8-1a and 8-1b) and the probability distributions used for eruptive power, duration, and tephra density. The resulting tephra volume distribution and associated statistics are shown in Figure 1. Because eruption duration and power are sampled using a log-uniform distribution, the erupted tephra volume shown in Figure 1 follows a similar distribution. As shown in the figure, values in the upper end of the range of tephra volumes have a relatively low probability of occurring. The figure also shows that the mean value of tephra volume is 0.038 km^3 and half of the sampled values are less than 0.024 km^3. These values reasonably represent the uncertainty in tephra volume and are consistent with the values of total volume shown in SAR Table 2.3.11-2.

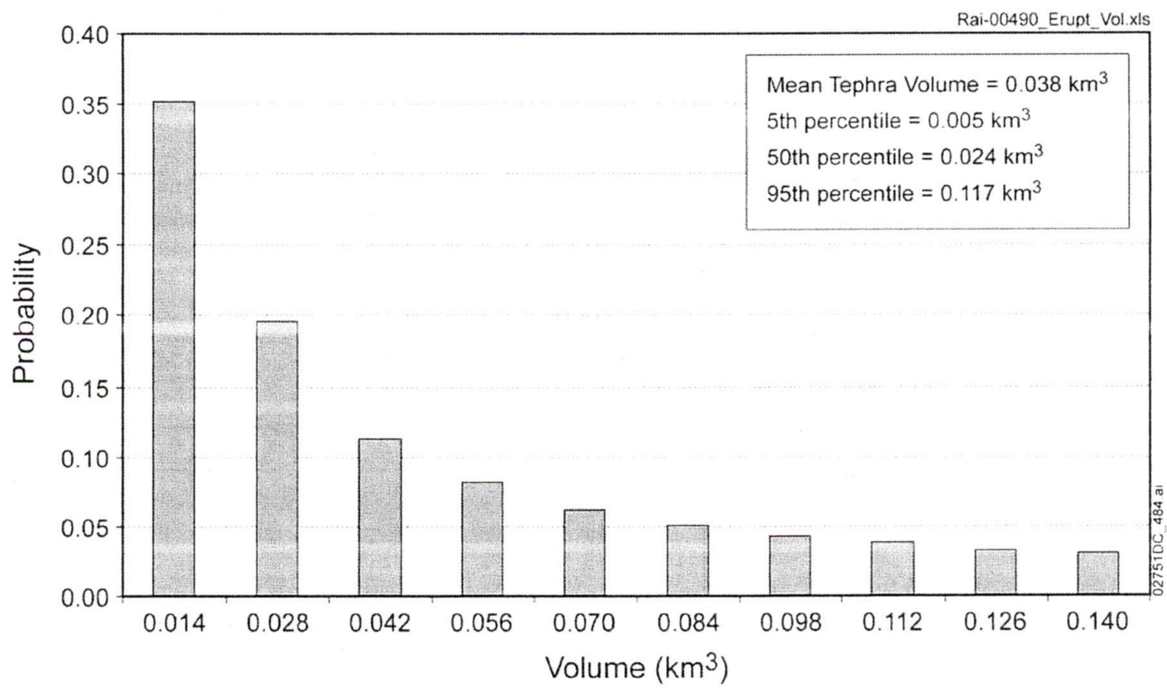

Figure 1. Probability Distribution and Statistics for Erupted Tephra Volume

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2007a. *Characterize Eruptive Processes at Yucca Mountain, Nevada.* ANL-MGR-GS-000002 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070301.0001; LLR.20080401.0273; DOC.20081001.0001.

SNL 2007b. *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada.* MDL-MGR-GS-000002 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071010.0003; LLR.20080522.0090.

RAI Volume 3, Chapter 2.2.1.4.2, First Set, Number 1:

Clarify the technical basis for the amount of water entering the waste package for the human intrusion scenario. Also, provide a comparison of the amount of water estimated to enter the human intruded waste package with the amount estimated to enter waste packages that have patch failures.

Basis: The SAR implies that the 'only' water that enters a waste package that is breached due to a human intrusion event is the water that enters the borehole (i.e., other seepage water does not enter the breached area caused by the intrusion). It is unclear as to why other seepage water that enters the drift could not enter the breached area of the waste package caused by the intrusion. The staff needs this information to determine compliance with 10 CFR Part 63.322.

1. RESPONSE

As detailed in SAR Section 2.4.3.1.2, the unsaturated zone borehole transport pathway in the human intrusion scenario is conceptualized to be an uncased borehole that undergoes natural degradation processes (including erosion and seismic events), resulting in rubble infill and wall rock collapse shortly after it is drilled. The use of the percolation flux at the base of the Paintbrush non-welded hydrogeologic (PTn) unit is used to determine the volumetric flow rate of water through the intruded waste package and is considered to be representative of steady-state conditions consistent with the conceptualization of the degraded borehole. The percolation flux at the base of the PTn unit is determined by the site-scale unsaturated zone flow model (SAR Section 2.3.2.1).

The only water entering the intruded waste package enters through a borehole along the apex (crown) of the waste package. The borehole opening in the top of the drift is expected to be directly above the opening in the intruded waste package; therefore, water dripping from the borehole in the top of the drift (e.g., percolation flux at the base of the PTn unit) is expected to intersect the waste package near or within the borehole opening. However, the assumption that the entire borehole flux enters the waste package neglects the effects of water being diverted from the borehole to the rubble material between the waste package and the drift crown. This assumption accounts for the possibility of any additional water flux from seepage dripping within the vicinity of the borehole. Adjacent seepage entering the waste package through the borehole is negligible, and is conservatively estimated at only about 3.5% of the mean water flow through the intruded waste package. Since it is likely that some of the borehole flow would be diverted around the waste package opening due to rubble infill and/or dispersal of the drips, adjacent seepage is captured within the assumption that all of the borehole flow exiting the borehole at the top of the drift is funneled into the drill patch opening in the top of the waste package.

The occurrence of an additional 3.5% of water flow through the intruded waste package will not significantly impact the mean annual dose projections for the human intrusion scenario. After the drilling intrusion event, there is an initial pulse of highly soluble, nonsorbing radionuclides, such as ^{99}Tc and ^{129}I, which dominate the maximum of the mean annual dose and account for about 99% of the maximum median annual dose (SAR Section 2.4.3.3.1). A small increase in the water flow rate through the intruded waste package would not increase the mass of ^{99}Tc and ^{129}I released. These radionuclides have high dissolved concentration limits and thus, all of the available mass is rapidly released into the borehole. After the pulse of highly soluble, nonsorbing radionuclides has passed through the system, the long-term dose to the reasonably maximally exposed individual (RMEI) drops to approximately 0.0002 mrem, which occurs primarily from ^{242}Pu with secondary contributions from ^{135}Cs and ^{237}Np (SAR Section 2.4.3.3.1). As outlined in SAR Section 2.4.3.4.3, the inputs that have the greatest influence on the uncertainty in expected annual dose following the human intrusion event are those identified for the transport of ^{99}Tc. Thus, dose projections for the human intrusion performance assessment support a finding that there is a reasonable expectation the mean annual doses to the RMEI would be well below the individual protection standard for human intrusion (SNL 2008, Section 8.1.3.2[a]).

Section 1.1 contains a discussion of the estimation of the indirect seepage into an intruded waste package, and Section 1.2 contains a comparison of the repository average amount of water entering the intruded waste package through a borehole to the amount of water entering a waste package through a patch in a nominal scenario.

1.1 ESTIMATE OF INDIRECT SEEPAGE THROUGH AN INTRUDED WASTE PACKAGE

An estimation of the mean water flux from impinging seepage that may enter the breached area of the waste package caused by the intrusion is provided in Table 1. The amount of seepage impinging on the waste package crown that may enter the borehole opening can be approximated using the results of the experimental data used to develop and validate the flux-splitting model used in the total system performance assessment (TSPA) Engineered Barrier System (EBS) flow submodel (SAR Section 2.4.2.3.2.1.6). Splash distances and fractions for dripping onto the crown of an experimental drip shield surface are listed in Section 7.1.1 of *EBS Radionuclide Transport Abstraction* (SNL 2007).

The splash radius data (SNL 2007, Figures 7.1-1 and E-3) were used to calculate a mean splash radius for dripping on the crown of 21.8 cm for the inner cluster and 50.6 cm for the outer fringe. The inner cluster represents the radius of the bulk or cluster of splash droplets that accumulate around the impact point, and the outer fringe represents the farthest drip splashed from the impact point. The distance a splashed droplet can travel is finite, limited by the kinetic energy of a falling drop. The area is estimated using the mean splash radius of the inner cluster and outer fringe. Additionally, an estimate of the fraction of the dripping flux along the crown that may enter the test patch opening was provided (BSC 2003, Appendix B). Compiling the data for test patch 6, which occurs along the crown of the test surface, and interpolating between the dripping points over an equal area domain, the average fraction of drips entering the test patch within the splash area can be approximated. Using the post-10,000-year repository average seepage from the nominal modeling case, 9.47×10^{-2} m^3/yr (see Table 5 in response to RAI 3.2.2.1.3.6-2-010), approximately 3.57×10^{-5} m^3/yr of the seepage impinging within the splash area around the borehole was estimated to potentially enter the waste package. Table 1 contains a summary of these estimates. The indirect seepage flux is approximately 3.5% of the mean water flux through a waste package in the human intrusion scenario (1.03×10^{-3} m^3/yr).

The estimate of indirect seepage flux provides a quantitative evaluation of the basis for excluding other seepage water that enters the drift from entering the breached area of the waste package caused by the intrusion.

Table 1. Estimation of Additional Water Flux through a Borehole from Seepage

Location	Mean Splash Radius (cm)	Splash Area (m^2)	Drips into Borehole Patch (%)	Seepage in Splash Area (m^3/yr)	Seepage into Borehole Patch (m^3/yr)	Indirect Flux/ Borehole Flux (%)
Inner Cluster	21.8	0.45	2.23	1.50×10^{-3}	3.35×10^{-5}	3.26
Outer Fringe	50.6	1.12	0.13	3.78×10^{-3}	2.20×10^{-6}	0.21
TOTAL	—	1.57	—	5.29×10^{-3}	3.57×10^{-5}	3.48

Source: Spreadsheet: *Interpolation and Statistics for Percentage of Drop in Patch_v2_07_06_2009.xls*.

1.2 COMPARISON OF WATER FLUX THROUGH A INTRUDED WASTE PACKAGE WITH A NOMINAL PATCH OPENING

Table 2 compares the mean water flux through a borehole patch in the human intrusion scenario to the water flux through a patch failure in the nominal scenario. Water flux through the borehole opening in the waste package for the human intrusion scenario ranges from 4.78×10^{-4} to 2.28×10^{-3} m^3/yr based on the 5th and 95th percentile values of the distribution and has a mean value of 1.03×10^{-3} m^3/yr.

Using the post-10,000-year repository average seepage per waste package from the nominal modeling case, with a mean of 9.47×10^{-2} m^3/yr and 5th and 95th percentile values of 8.81×10^{-3} and 3.24×10^{-1} m^3/yr, respectively (see Table 5 in response to RAI 3.2.2.1.3.6-2-010), the calculated seepage flux through a single patch in the nominal scenario class varies from 1.42×10^{-4} to 5.22×10^{-3} m^3/yr based on the 5th and 95th percentile values of the seepage flux distribution and has a mean value of 1.53×10^{-3} m^3/yr. The ratio of the borehole opening (drill patch area is 0.0324 m^2) to the nominal patch area (0.02315 m^2) is approximately 1.4. The calculated seepage flux through 1.4 patches ranges from 1.99×10^{-4} to 7.30×10^{-3} m^3/yr, based on the 5th and 95th percentile values of the seepage flux distribution, and has a mean of 2.13×10^{-3} m^3/yr. The mean seepage flow through a single nominal patch is higher than the mean water flow through the human intrusion borehole. This is due to the uncertainty in the flux splitting model in the TSPA EBS flow submodel (SNL 2008, Section 6.3.6). The values in Table 2 are reported for the median value results for the flux splitting model uncertainty.

As described in Section 6.3.2.4 of *EBS Radionuclide Transport Abstraction* (SNL 2007), observations during the drip tests used as the basis for the waste package flux splitting model revealed that the primary mechanism for water entering breaches is via rivulet flow that originates from an area around the point of drip impact. Drips closest to the downhill curvature reach a critical mass and roll down the face of the waste package in the form of a rivulet. The rivulet flow area spreads out in a delta formation (i.e., the maximum spread is located on the vertical section of the waste package, and the minimum spread is located at the crown, which is assumed to be the point of impact). Since nominal patch breaches in the waste package are randomly located, the fraction of dripping flux falling on the waste package that flows into the waste package might be expected to be proportional to the total area of waste package patches, as is the case for the waste package flow through the borehole opening in the human intrusion scenario. However, since patches are randomly located in the nominal scenario, drips that fall onto a waste package surface are likely to drain down the surface before entering a patch opening. Therefore, the flux of water (i.e., rivulets flowing down the surface of the waste package) intercepted by patches, and thereby entering a waste package, is determined by considering the uncertainty in the rivulet spread angle and ignoring interference by multiple patches (SNL 2007, Section 6.3.3.2.5). This model predicts more flow than a flow model that is proportional to the total area of waste package patches. As described in SAR Section 2.4.2.3.2.1.6, the flow splitting fraction reaches a value of 1 (i.e., all the impinging flow can enter a waste package) well before the number of patches reaches its maximum. For the mean value of 1.2 for the waste package flux-splitting uncertainty distribution, only about 62 general corrosion patches (out of a total of 1,430) are required on a commercial spent nuclear fuel waste package to allow 100% of the impinging flow to enter a waste package (SNL 2008, Section 6.3.6.2). This is only 4% of the area of the waste package (excluding the lids). The flux splitting model used in the nominal scenario to determine the amount of seepage flowing down the sides of a breached waste package that may intersect a patch opening is not applicable in the human intrusion scenario, where the location of the borehole breach in the intruded waste package always occurs along the waste package crown (SNL 2008, Section 6.7.2.3.3).

In the human intrusion scenario, where the drill patch opening occurs along the crown of the waste package, the fraction of dripping flux falling on the crown of the waste package that flows into the waste package is expected to be proportional to the area of patch opening. Using the post-10,000-year repository average seepage from the nominal modeling case, 9.47×10^{-2} m^3/yr without the flux splitting model, the calculated seepage flux through a single patch in the nominal scenario class is lower, varying between 7.27×10^{-6} and 2.67×10^{-4} m^3/yr, based on the 5th and 95th percentile values of the seepage flux distribution, and having a mean value of 7.82×10^{-5} m^3/yr. Likewise, the calculated seepage flux through 1.4 patches is reduced to a range between 1.02×10^{-5} and 3.74×10^{-4} m^3/yr, based on the 5th and 95th percentile values of the seepage flux distribution, with a mean of 1.09×10^{-4} m^3/yr.

Table 2. Comparison of Water Flux through a Borehole Opening and a Nominal Patch – Post-10,000 Years

Post-10,000-Year Repository Average Flow Rates (m^3/yr/waste package)			
	5th percentile	Mean	95th percentile
Human Intrusion Modeling Case			
Mean flow through human intrusion borehole	4.78×10^{-4}	1.03×10^{-3}	2.28×10^{-3}
Nominal Modeling Case - Mean Seepage			
Flow through single nominal patch	1.42×10^{-4}	1.53×10^{-3}	5.22×10^{-3}
Flow through 1.4 nominal patches	1.99×10^{-4}	2.13×10^{-3}	7.30×10^{-3}
Nominal Modeling Case - Mean Seepage (without flux splitting model)			
Flow through single nominal patch	7.27×10^{-6}	7.82×10^{-5}	2.67×10^{-4}
Flow through 1.4 nominal patches	1.02×10^{-5}	1.09×10^{-4}	3.74×10^{-4}

Source: Percolation flux from Table 3 of response to RAI 3.2.2.1.3.6-005; nominal seepage from Table 5 of response to RAI 3.2.2.1.3.6-2-010; and spreadsheet: *HIFluxvsFulxSplit_v1.xls*.

1.3 SUMMARY

The use of the percolation flux at the base of the PTn unit to determine the volumetric flow rate of water through the intruded waste package is considered to be representative of steady-state conditions consistent with the conceptualization of the degraded borehole.

An estimation of the mean water flux from impinging seepage that may enter the breached area of the waste package caused by the intrusion is approximately 3.5%. A comparison of the mean water flux through a borehole patch in the human intrusion scenario to the water flux through a single patch failure in the nominal scenario shows that the mean flow through the borehole opening in the intruded waste package is lower than the mean seepage that could flow through a single patch in the nominal modeling case which includes the effects of flux splitting model. Without the flux splitting model, the mean flow through a single patch in the nominal modeling case is much lower than the mean flow through the borehole opening in the intruded waste package. The occurrence of any additional water flux through the intruded waste package as a result of impinging seepage near the borehole breach is captured in the analyses and will not impact the peak mean annual dose projections for the human intrusion scenario.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2003. *Atlas Breached Waste Package and Drip Shield Experiments: Breached Drip Shield Tests.* TDR-EBS-MD-000025 REV00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030619.0001.

SNL (Sandia National Laboratories) 2007. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20071004.0001.

SNL 2008. *Total System Performance Assessment Model/Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001.